

Decision-Support for the Economic Analysis of Trade-offs in Coastal and Marine Spatial Planning (CMSP) for the US Northeast Shelf Large Marine Ecosystem

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Abstract: Coastal and marine spatial planning (CMSP) is a process for improving the management of coastal and marine resources in order to promote their sustainable development. Sustainability necessitates that decisions be made about existing and future spatial and temporal distributions of human uses (and non-uses) of the coastal and marine environment. Such decisions require methods for making tradeoffs. We present the outlines of an economic methodology based upon models of spatially distributed regional economic impacts to characterize the social welfare effects of tradeoffs among alternative CMSP policies. We show how a regional computable general equilibrium (CGE) model of the US northeast coastal economy could be used to assess changes in the spatial and temporal distribution of human uses and activities in the US Northeast Region. This work extends earlier efforts to develop a regional input-output (IO) model of the Northeast Shelf LME and to link a regional IO model to linear models of a marine food web. The resulting CGE model could be used to analyze marginal changes in social welfare with respect to policy changes and to evaluate tradeoffs by estimating the socio-economic net benefits of alternative scenarios. We present some examples of how the model could be used to simulate tradeoffs such as those involving the siting of ocean wind farms.

Keywords: coastal and marine spatial planning; trade-offs; regional economic model; Northeast Shelf Large Marine Ecosystem (LME); commercial fisheries; renewable energy siting

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1. Introduction

We present a framework for analyzing the social welfare effects of tradeoffs among alternative coastal and marine spatial planning (CMSP) policies (or allocations). We show that (1) recent developments in model building and modeling software have made linked economic-ecological analysis possible at the multi-sector level; (2) a useful approach to developing multi-sector economic and ecological analyses is to utilize existing state-of-the-art economic models (*e.g.*, computable general equilibrium (CGE) models) and food web models; and (3) the economic opportunity costs of the siting of non-transitory uses of the coastal ocean can be evaluated with applications of comparative statics using these models.

We have developed an integrated economic-ecological framework by linking a CGE model of a coastal economy to an end-to-end (E2E) model of a marine food web for Georges Bank (Collie *et al.* 2009). Here, we extend our basic model of the economic and ecological systems in coastal New England by analyzing the socio-economic impacts of the displacement of commercial fisheries from an ocean area to be occupied by a renewable energy facility. We note that the conceptual framework described in this paper has not been fully implemented. We plan to elaborate the links between economic and ecological models in future work.

2. An Economic-Ecological Framework¹

The importance of integrated economic-ecological analysis has been stressed by many experts (Arrow *et al.* 1995). Most classical bioeconomic models involve the dynamic control of nonlinear biosystems (Clark 1976). An advantage of this approach is that it can be used to conduct both positive and normative analyses. A disadvantage is that these models include only a small number of variables (*e.g.*, biomass of only a few species and either fishery yield or fishing effort).

In order to analyze systems with a larger number of interacting elements, such as industries and consumers in an economy, or species in an ecosystem, economists and ecologists have explored the use of linear models (*e.g.*, IMPLAN and ECOPATH). Economic input-output (IO) models have been developed for the northeast coastal region (Hoagland *et al.* 2010, 2005), and marine food web models have been developed for the Georges Bank ecosystem (Collie *et al.* 2009; Link *et al.* 2008; Sissenwine *et al.* 1984).² Following Isard *et al.* (1968), Jin *et al.* (2003) have developed a procedure for merging a regional input-output model of a coastal economy with a linear model of a marine food web. Although linear IO models can incorporate a large number of industry sectors, they are limited to descriptive

¹ The discussion in this section reprises the discussion of Jin (2011), who focuses on the use of the CGE framework for analyzing changes in fishery yields and open-ocean aquaculture production, and Jin *et al.* (2010), who focus on the use of the framework for analyzing the effects of implementing fishery conservation and management measures.

² For an excellent review of different food web models, see Plagányi (2007).

applications. In particular, they cannot be used to develop normative welfare estimates relevant to policy analysis.

The CGE framework permits the examination of a smaller number of sectors, relative to IO models, but the methodology allows the analysis of normative changes. CGE models have been developed to include environmental and natural resource sectors (Abler *et al.* 1999; Xie *et al.* 1996). Several CGE models have been developed specifically for fishery studies (Waters and Seung 2010; Pan *et al.* 2007; Chiang *et al.* 2004). Recent developments in linking dynamic economic and ecological general equilibrium models can be found in Finnoff and Tschirhart (2008). A fundamental tradeoff exists between the number of variables and the nonlinear dynamics. As a consequence, we must carefully examine linkages between ecological and economic systems in order to identify the key economic sectors to be modeled explicitly for specific purposes.³

The economic-ecological framework that we develop is an extension of the traditional bioeconomic approach. Our approach is designed to characterize existing economic and ecological conditions and to demonstrate changes in social welfare that may result from

³ For example, the CGE model by Waters and Seung (2010) includes 2 fish harvesting sectors, two fish processing sectors, and other aggregate sectors in the economy. In contrast, the partial equilibrium model by Chiang (2005) is focused on the fishery sector, which consists of 40 products and 68 fishing activities.

changes in the consumption of marine resources, goods, and services (*cf.*, Edwards and Murawski 1993).

The major features of an economic CGE model include the following: (1) prices are endogenous and are determined by the market; (2) supply and demand for goods and production factors are equated by adjusting prices based on Walrasian general-equilibrium theory; (3) supply and demand functions are derived from the behavior of profit-maximizing producers and utility-maximizing consumers; and (4) the model is multi-sectoral and nonlinear with resource constraints (Xie & Saltzman, 2000).

A basic CGE model has N industry sectors ($j = 1, 2, \dots, N$) that supply goods to two demand sectors: household and government. The household sector provides capital (K) and labor (L) to the industry sectors. Suppose each industry sector j produces a specific commodity j , the supply and demand of commodity j is depicted in Fig. 1.

Production is typically modeled through a nested structure. On the first level, the producer chooses the levels of capital and labor inputs so that the level of composite factor input (i.e., value added) is optimized. Specifically, the producer maximizes the profit subject to production technology F_{Yj} :

$$\max P_{Yj} Y_j - P_L L_j - P_K K_j \quad s.t. \quad Y_j = F_{Yj}(L_j, K_j) \quad (1)$$

where L_j , K_j and Y_j are the quantities of labor, capital, and composite factor respectively, used in producing commodity j . P_L , P_K and P_{Y_j} are the prices of L , K and Y_j respectively. The functional form of F_{Y_j} is typically either CES (constant elasticity of substitution) or Cobb-Douglas. The levels of factor inputs (L_j and K_j) are calculated using the first order conditions of problem (1).

On the second level, the composite factor (Y_j) is combined with intermediate inputs (X_{ij}) to produce output (Z_j).

$$Z_j = F_{zj}(Y_j, X_{1j}, X_{2j}, \dots, X_{Nj}) \quad (2)$$

where X_{ij} ($i = 1, 2, \dots, N$) is commodity i used in the production of j . For example, if Z_j is the output from commercial fishing, X_{ij} represents food, fuel, or ice used in fishing. In the basic model, the functional form for F_{zj} is Leontief in which Y_j and X_{ij} are in fixed ratios. For a given level of composite factor input (Y_j), local output (Z_j) is determined.

In the middle section of Fig. 1, trade is added to the commodity's supply and demand. The producer in the study region sells its output to both the local market and markets outside of the region. In addition to local production, commodity j is also imported from outside the region. On the right side of Fig. 1, the household sector maximizes its utility (U) of consumption (X_c) subject to income constraint:

$$\max U(X_{C1}, X_{C2}, \dots, X_{CN}) \quad s.t. \quad \sum_j P_{Qj} X_{Cj} = P_L L + P_K K \quad (3)$$

The functional form for U is typically Stone-Geary or Cobb-Douglas. The levels of consumption (X_{cj}) are calculated using the first order conditions of problem (3).

There are two basic approaches to formulate a food web model for a specific ecosystem. Steele (2009) provides a review of these alternative approaches. Both formulations start from the following equation stating that the change in biomass at time t equals the sum of gains from all sources minus all losses:

$$\frac{dB_i}{dt} = e_i \left(\sum_j Q_{ij} + G_i \right) - \sum_k Q_{ki} - L_i \quad (4)$$

where B_i is the biomass of trophic component i , Q_{ij} is the rate at which B_j is consumed by B_i , G_i is the gains from external sources; L_i is the losses from the system (e.g., fishing), and e_i is the transfer efficiency.

The two types of models differ in the way in which Q_{ij} is modeled. In a donor-controlled model, Q_{ij} is a function of production, P_i , in each of the i trophic components. In contrast, in a recipient-controlled model, Q_{ij} is a function of consumption, C_i , in each of the i trophic components. Note that P_i and C_i are both flows, while B_i is a stock.

At steady-state, the donor-controlled formulation of Equation (4) is

$$P_i = e_i \left(\sum_j a_{ij} \cdot P_j + G_i \right) - f_i \cdot P_i \quad (5)$$

where P_i is the production in trophic component i , a_{ij} is the fraction of P_j flows to P_i , and f_i is the fractional loss of P_i to the system. Fish harvesting is modeled in the last term in (5). In the above formulation, production at the lower trophic levels (P_j) determines the production at the upper trophic levels (P_i). Thus, a donor-controlled model is also called a “bottom-up” model. Bottom-up models typically have been designed to capture the effects of changes in primary production associated with environmental perturbations, such as those associated with climate change.

In a recipient-controlled (“top-down”) formulation, at steady state, Equation (4) becomes⁴

$$e_i \cdot C_i = \sum_k b_{ik} \cdot C_k - e_i G_i + L_i \quad (6)$$

where C_i is consumption by trophic component i , b_{ik} is the fraction of C_i that is consumed by species k . Note that consumption by k , C_k , is at the upper trophic level, and it is consumption at the upper trophic levels that influences consumption at lower trophic levels. In a top-down formulation, fish harvesting is modeled in the last term (L_i). Top-down models typically have been designed to assess the impacts of fish harvesting on other ecosystem components and processes.

⁴ The derivation of this equation is provided in Steele (2009: 187).

As the commercial fishing industry harvests fish from the ecosystem, we can link a marine food web model with the economic CGE model using the classical harvest function often used in bioeconomic analysis:

$$Y = qEB \quad (7)$$

where Y is the quantity of fish harvested, q is a catchability coefficient, E is fishing effort [= $F(L, K)$], and B is the stock biomass modeled in the food web [see Equation (4)]. According to Equation (7), for a fixed catchability and a given level of fishing effort, harvest is proportional to stock biomass.

We model the effect of changing stock size (B) by modifying the production function for the fishing sector in the CGE model:

$$Y_j = \alpha F_{Yj}(L_j, K_j) \quad \text{for } j = \text{fishing} \quad (8)$$

Alternative ecosystem states and associated stock levels x are incorporated into the shift parameter α . For example, under the baseline conditions 0, $\alpha = 1$. When x increases, $\alpha > 1$. This, in turn, leads to an adjustment in fishing effort, which is a function of capital and labor inputs in the CGE model. The economy-wide effects of stock variation are then estimated by the CGE model (Fig. 2).

The feedback from the economic model to the food web model can be modeled using Equation (5). For a change in fish catch f_i , we can re-estimate the corresponding changes in

the productions and consumptions in different trophic components throughout the food web. Equation (5) can be rewritten in matrix notation as:

$$\mathbf{P} = (\mathbf{I} - \mathbf{IeA} + \mathbf{If})^{-1} \mathbf{IeG} \quad (9)$$

If there are n trophic components in the food web, then \mathbf{P} , \mathbf{e} , \mathbf{f} and \mathbf{G} are $n \times 1$ vectors, \mathbf{I} is a $n \times n$ identity matrix, and \mathbf{A} is a $n \times n$ matrix. Thus, the change in fish catch can be modeled as a change in the vector \mathbf{f} , and the production vector \mathbf{P} can be easily calculated.⁵

3. Regional CGE Model and Baseline Data

We examine the economic effects of the displacement of commercial fishing as a consequence of the siting of renewable energy facilities. To do this, we adapt a regional CGE model by Stodick *et al.* (2004), which takes IMPLAN data as input. IMPLAN is a modular IO model that works down to the individual county level for any county in the United States. IMPLAN data are updated annually and contain national income and employment statistics for over 500 economic sectors, including commercial fishing and seafood processing. The IMPLAN sectors also can be aggregated into broader sectors (MIG 2000).

⁵ Note that the standing stock biomass (B) can be calculated from production rate (P) using the P/B ratio. A specific example on how to estimate changes in fish harvesting resulting from changes in production (P) can be found on page 2228 of Collie *et al.* (2009).

We have assembled a CGE model of the New England coastal economy using county-level data from IMPLAN. The model includes five sectors: commercial fishing, seafood processing, agriculture, manufacturing, and an aggregate sector of all other sectors combined. The baseline output, supply, and trade statistics calculated with the CGE model of the New England coastal economy are summarized in Table 1. The output from the fishing sector is \$870 million. The total fish commodity supplied to the New England regional market (Q) is \$653 million, which is equal to the local output (Z) of \$870 million plus imports (M) of \$42 million minus exports (E) of \$259 million to foreign countries. The output from fish processing is \$1.12 billion, of which \$708 million is exported to markets outside New England; the remainder, when combined with imports, is supplied to local market (\$543 million).

4. Simulation of the Welfare and Distributional Effects of Renewable Energy Siting

Here, we examine the effect of the reallocation of coastal ocean areas from commercial fishing to renewable energy production. We provide a very simple example of how the CGE framework might be utilized. We consider only the displacement of commercial fishing from an area of the exclusive economic zone in the Northeast Shelf LME. We do not model the net benefits of the generation of electricity from a renewable energy facility.⁶ A more de-

⁶ The siting of renewable energy facilities in the ocean is believed to be a marginally productive activity. In most cases, these facilities require subsidies, and therefore they are unlikely to yield net surpluses.

tailed analysis would want to consider the net gains (if they exist) from renewable energy generation, the net losses from displaced fisheries, and the implications of the dynamics of fish stocks and fishing effort in areas both within and outside the renewable energy area.

We assume that commercial fishing is disallowed in the areas designated for renewable energy. This assumption is a strong one, as there is currently a discussion among federal and state regulatory bodies about whether uses such as commercial fishing should be permitted in areas designated for renewable energy development. At the very least, some forms of fishing, such as trawling or longlining, will be difficult—if not hazardous—to carry out in the vicinity of permanent structures. Other forms of fishing, such as pots or gillnets, may be more compatible with renewable energy.

We further assume that a fixed percentage of the total fishing area in the US northeast is closed to commercial fishing. Such a closure translates into a percentage reduction in fishery yields from the total area. This assumption could be made more precise with specific information about the locations of historical catches and leases for renewable energy development. While broad leasing areas have been identified and put forward (Fig. 3 presents an example south of Nantucket Island off the coast of Massachusetts), no specific lease sales have been undertaken yet. Consequently, our simulation is an example of how the CGE framework can be utilized; it is not an analysis of a specific spatial allocation proposal.

Finally, we do not model the dynamics of either fish stocks or fishing effort. It is probable that areas closed to commercial fishing could serve as a fishery reserve. Unexploited fish stocks inside a reserve might eventually become a source of exploitable fish to areas of the fishery that remain open. Further, displaced fishermen are likely to turn their efforts to other areas that remain open, and, *ex ante*, the effects on fishery yields are uncertain. These types of effects would need to be examined in more detail within the context of a specific planning or zoning decision.

When programmed into the CGE framework, proportional reductions in fishery yields result in consumer and producer surplus losses. The CGE framework measures these losses as changes in “equivalent variation,” which is a type of economic welfare measure. As currently structured, the CGE framework depicts the distribution of these surplus losses across household income categories. Table 2 presents the total surplus losses across income categories for three hypothetical alternative area allocations (2, 5, and 10% of the existing commercial fishing grounds).

The estimates presented in Table 3 are interesting in at least two ways. First, the size of the surplus losses are small, given the nearly \$1 trillion regional economy of New England in 2006 (Table 1). Even the 10% reduction scenario yields only \$130 million in surplus

losses. While it is not quite correct to compare surpluses with direct outputs, this loss represents only about one-tenth of one percent of the regional economy.

Second, the *nominal* losses appear to be progressively distributed, with higher income households shouldering more of the losses. The reason for the progressive effect is that households with higher incomes tend to consume more seafood because it is a relatively high priced form of protein. A closer look at the individual welfare effects, however, suggests that on average, lower income households are impacted more than those with higher incomes. There are fewer low income than high income households and, by definition, the incomes of the former are smaller. Fig. 4 demonstrates this effect. Let H_i equal the total number of households in each income level, i . For each income level, the average household impacts, I_i , in Fig. 4 are calculated as the average welfare change per household EV_i/H_i , relative to the average income, Y_i , per household:

$$\overline{I}_i = \frac{\left(\frac{EV_i}{H_i} \right)}{\overline{Y}_i} \quad (10)$$

Fig. 4 demonstrates a regressive effect on average for the lower income households when 10% of the commercial fishing area is allocated for renewable energy generation. Note that the impacts seem small, ranging from \$3 per household at the lowest income level to almost \$80 per household at the highest income level. While such impacts appear minor, consumer

advocates have been critical of even smaller effects, such as the projected increase in household electrical bills of between \$6-\$16 annually from the operation of the proposed Cape Wind renewable energy facility in Nantucket Sound (Ailworth 2010).

5. Summary

Decisions about existing and future spatial and temporal distributions of human uses (and non-uses) of the coastal and marine environment require methods for making tradeoffs. CMSP is a process for improving the management of coastal and marine resources to promote their sustainable development through the analysis of tradeoffs.

We present the outlines of an economic methodology based upon models of spatially distributed regional economic impacts to characterize the social welfare effects of tradeoffs among alternative CMSP policies. We show how a regional computable general equilibrium (CGE) model of the US northeast coastal economy could be used to assess changes in the spatial and temporal distribution of human uses and activities in the US Northeast Region.

This work extends earlier efforts by the authors to develop a regional input-output (IO) model of the Northeast Shelf LME and to link a regional IO model to linear models of a marine food web. The resulting CGE model could be used to analyze marginal changes in so-

cial welfare with respect to policy changes and to evaluate tradeoffs by estimating the socioeconomic net benefits of alternative scenarios.

We present an example of how the model could be used to simulate tradeoffs such as those involving the siting of renewable energy facilities and the prosecution of commercial fisheries. The example makes some strong assumptions about mutual exclusivity between uses, ignoring the dynamics of fish stocks and fishing effort, and focusing only on the potential welfare effects of reductions in fishery yields proportional to areas closed to allow renewable energy facility siting. Future research can be directed usefully at relaxing our assumptions, incorporating additional ocean uses, and, in general, improving the framework for potential use in contexts of decision support for CMSP.

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**Table 1: New England Coastal Regional Economy: Baseline Economic Value
(2006 \$ millions)**

Sector/Commodity	Output	Total Supply*	Imports**	Exports**
Agriculture	2,428	7,790	5,734	498
Fishing	870	653	42	259
Fish Processing	1,124	543	126	708
Manufacturing	194,703	247,124	90,030	37,608
Other	750,325	673,199	131,211	208,336

*Composite commodity supplied to New England market

**Including both domestic and foreign trade

Table 2: Welfare Impacts of Excluding Commercial Fishing from Renewable Energy Facilities in the Northeast Shelf LME

(lost equivalent variation for three proportional area closures: 1, 5, and 10%)

(\$m 2006)

Income Level	1%	5%	10%
< 10K	-0.093	-0.463	-0.953
10-15K	-0.190	-0.927	-1.824
15-25K	-0.543	-2.643	-5.164
25-35K	-0.740	-3.594	-7.019
35-50K	-1.606	-7.827	-15.292
50-75K	-3.107	-15.071	-29.392
75-100K	-2.452	-11.924	-23.273
100-150K	-2.765	-13.365	-26.058
150K+	<u>-2.331</u>	<u>-11.296</u>	<u>-22.024</u>
TOTAL	-13.826	-67.110	-130.999

Fig. 1: Basic Components of a CGE Framework

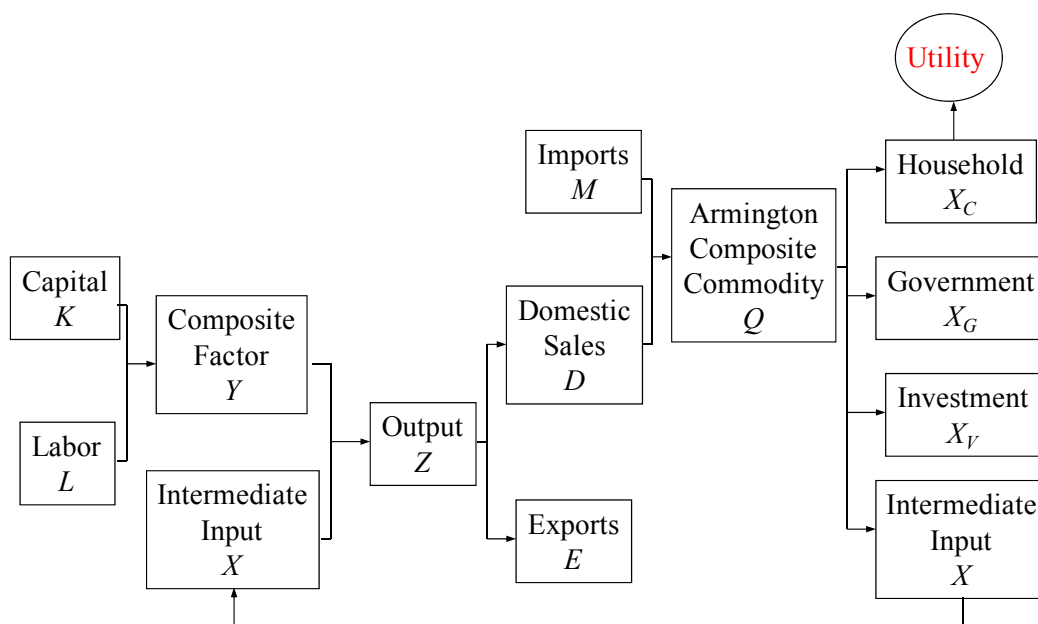


Fig. 2: Linking of a CGE Framework with a Marine Ecosystem Model

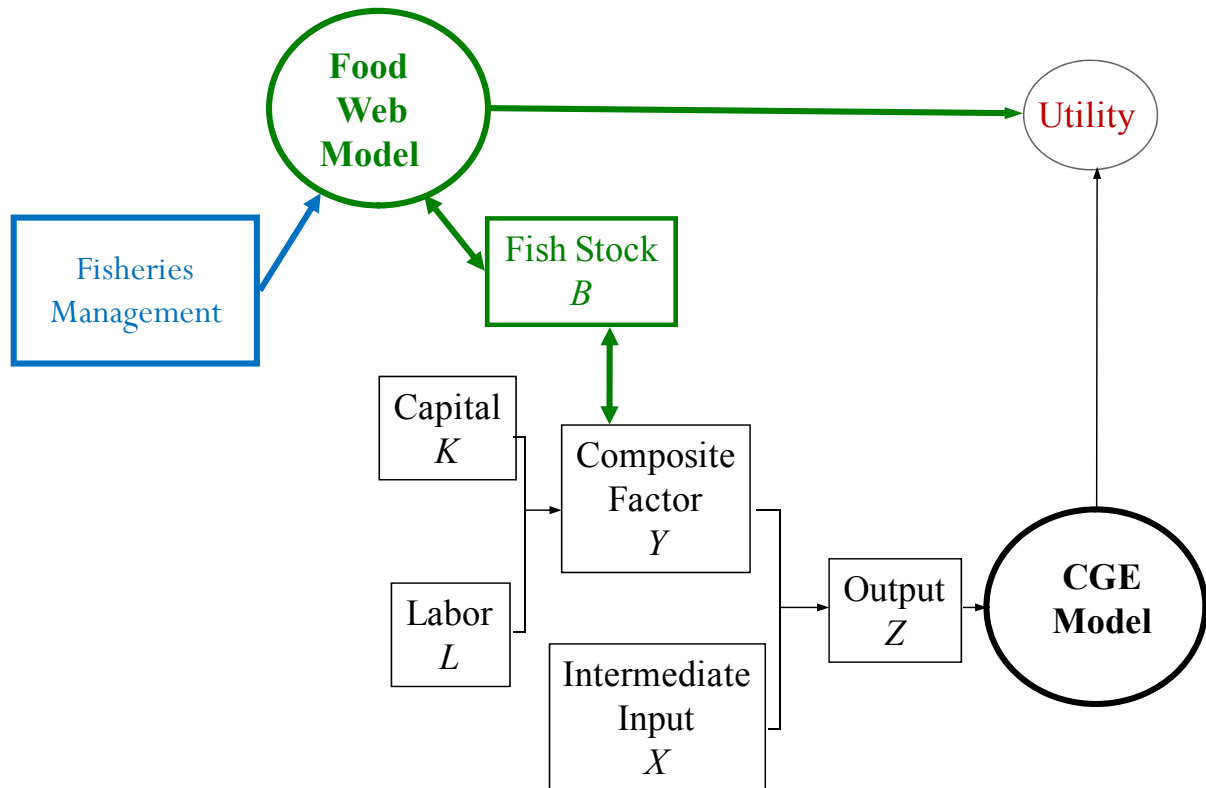


Fig. 3: Example of a Proposed Federal Renewable Energy Leasing Area

(Source: BOEMRE)

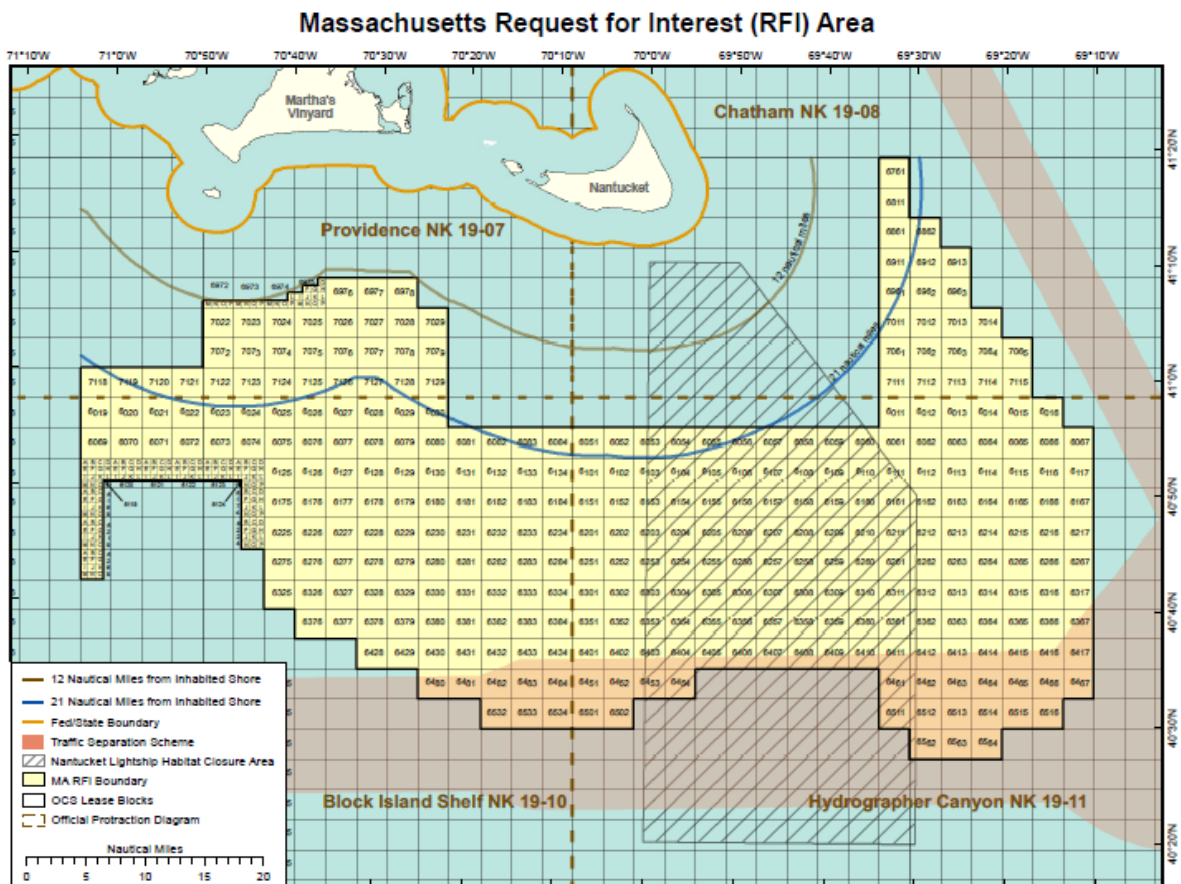


Fig. 4: Distribution of Welfare Impacts from the Displacement of Commercial Fisheries

